Brienne Johnson
Florida Space Grant Consortium

Materials Evaluation for Novel Concepts in Radiation Shielding

Brienne S. Johnson
Kennedy Space Center, FL

Note: Due to the intellectual property involved in the research carried out this summer several specifics of the work performed have been omitted because it is not public information and is being withheld from public disclosure under 35 U.S.C. §205. Information contained in this report can be used by the NASA Florida Space Grant Consortium to showcase project to our State's Congressional delegates and NASA HQ.

I. Summer Overview

What another amazing summer! I was truly excited when I heard about the Florida Space Grant Consortium (FSGC) Internship Program through the Kennedy Space Center (KSC) Education Office. It has been a privilege to return to KSC after my summer 2011 internship and work with the Materials Science Division, Chemical Analysis Branch (NE-L6) in the Engineering Directorate. This was an excellent way for me to prepare to enter the graduate program in the Materials Science and Engineering Department at the University of Florida in the fall while contributing to the Nation's Space Program.

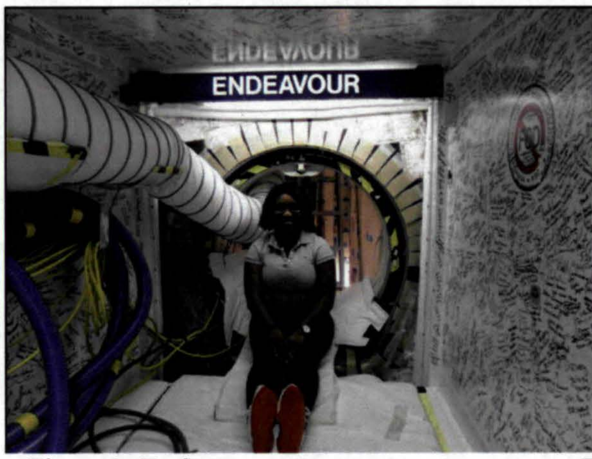


Figure1: Endeavor

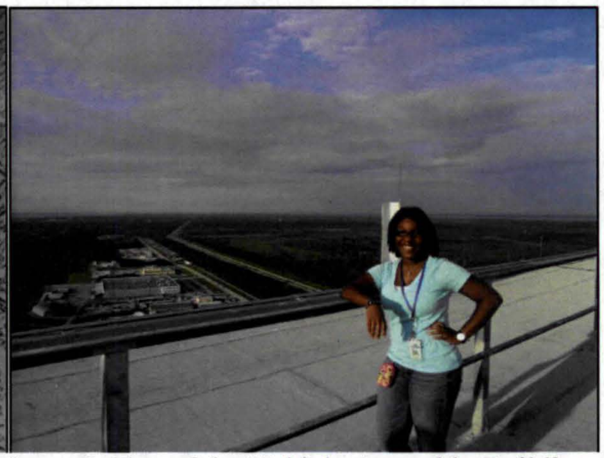


Figure 2: Top of the Vehicle Assembly Building

The research sponsored program lasted 10 weeks beginning June 4th and ending August 10th. My mentors were Dionne Jackson, Lead Chemist, and Dr. Martha Williams, Lead Polymer Scientist of the Polymer Science and Technology Laboratory (PSAT). The diverse PSAT group focuses on multiple research projects which address the development of specialty materials and systems to meet NASA's future needs in areas such as self healing and damage detection, repair systems for wiring, novel concepts in radiation shielding and novel thermal materials. I also had the opportunity to work with other laboratories in the Materials Science Division, the Cryogenics Test Laboratory (CTL), and researchers from the Engineering Support Contractor (ESC), QinetiQ North America.

Working with the different laboratories and disciplines allowed me to learn from a multi-faceted group of scientist and engineers; and assist with multiple research projects while still meeting the goals of my primary research project assignment. Additionally, this experience helped to further my academic and career goals. As a recent graduate with a Bachelors of Science in Chemistry, it afforded me the opportunity to apply my academic training and proved to be an excellent transition into my doctoral studies in Materials Science and Engineering this August. The different experimental techniques that I learned will be beneficial for my graduate studies and excellent training experience for my career goal. I gained enormous hands-on experience in the following materials characterization techniques: infrared spectroscopy (IR), thermogravametric analysis (TGA), ultra-violent visible and near infrared spectroscopy (UV Vis/NIR), scanning electron microscopy (SEM), Cup Cryostat (a unique KSC developed technology for evaluating thermal conductivity of materials at cryogenic temperatures), and solar/IR reflectometer. The Cup Cryostat is a patented KSC technology and a unique capability which is it expected to be included in ASTM standard methods in the coming years.

Although the summer was demanding due to the work in the different laboratories, I also had the privilege to go on some very interesting tours with other interns and learned many interesting and historical facts about KSC. Several of the exciting places I toured were the Launch Control Center, Vehicle Assembly Building (VAB), inside Endeavor in the Orbiter Processing Facility, and the Cape Canaveral Air Force Station. I also had the special opportunity to visit Embry-Riddle Aeronautical University (ERAU) in Daytona Beach with the team members from the PSAT and CTL labs in support of the Novel Materials and Methodologies for Transient Thermal Management project. FSGC provided funding this summer to ERAU for a joint KSC collaborative effort.

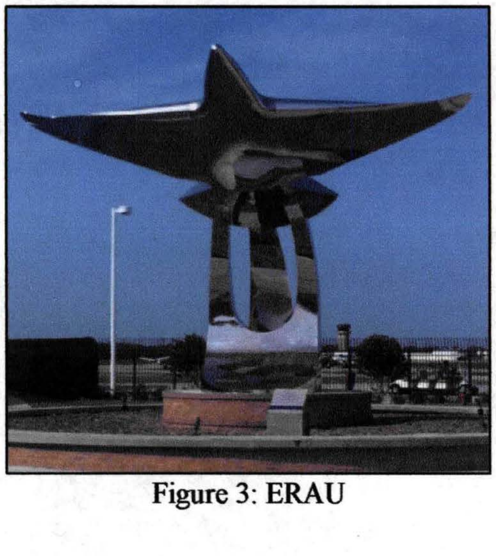


Figure 3: ERAU

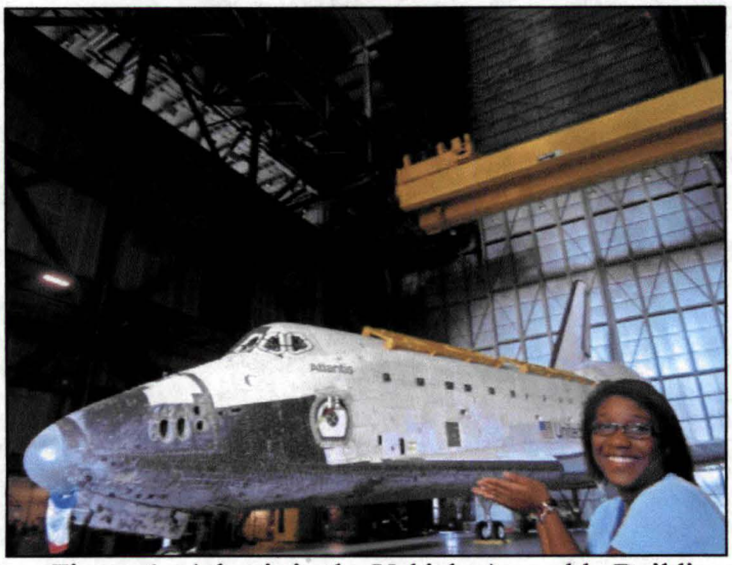


Figure 4: Atlantis in the Vehicle Assembly Building

II. Research Conducted

Radiation Shielding

In 2012, the National Research Council (NRC) of the National Academies identified the top technical challenges and highest priority technologies NASA needed to emphasize over the next 5 years in order to meet the goals of the 2011 NASA Strategic Plan.[1] The NRC considered the 14 draft technology roadmaps prepared by the NASA Office of Chief Technologist for their assessment. Of all of the technologies identified, Radiation Mitigation for Human Spaceflight was identified as one of the top priorities. Thus NASA and KSC are currently being funded to study approaches for possible solutions for shielding of Galactic Cosmic Radiation (GCR).

The focus of the research involved the testing and evaluation of state of the art and developmental thin-films that allow the containment of liquid hydrogen in new design and materials/systems concepts for novel radiation shielding. This data will be used to support concepts and decisions in the project. The films were tested using IR, UV Vis/NIR, and solar/IR reflectometer.

Infrared Spectrometry: IR was used to validate the chemical composition of each film, commercial and KSC developed. The films were tested using a Bio-Rad FT/IR instrument with Attenuated Total Reflectance (ATR) sample tester on the UMA 600 microscope accessory in reflectance. The chemical compositions of the films were validated using the Euclidean first derivative algorithm followed by comparison using the Sadler IR library database (Figure 5).

[1] National Research Council "NASA Space Technology Roadmaps and Priorities", National Academies Press, Washington, D.C., 2012.

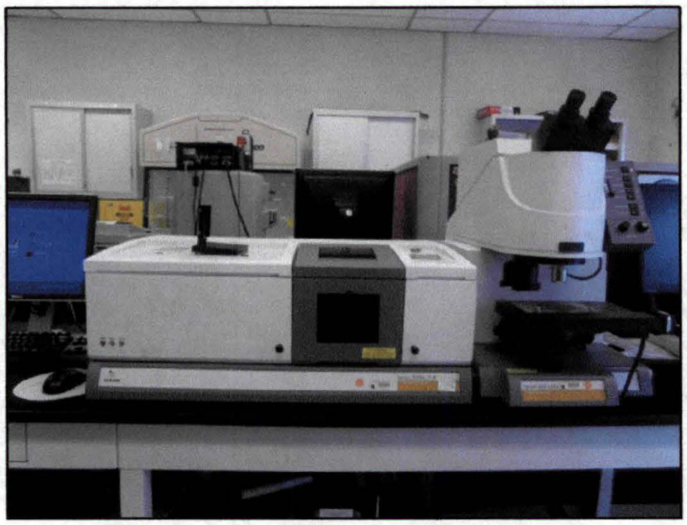


Figure 5: IR spectrometer instrument

Ultra-Violet Visible/Near Infrared: The JASCO V-670 UV Vis/NIR was used to determine where in the ultra-violent and near infrared wavelengths the films absorb the light they are exposed to (Figure 6).

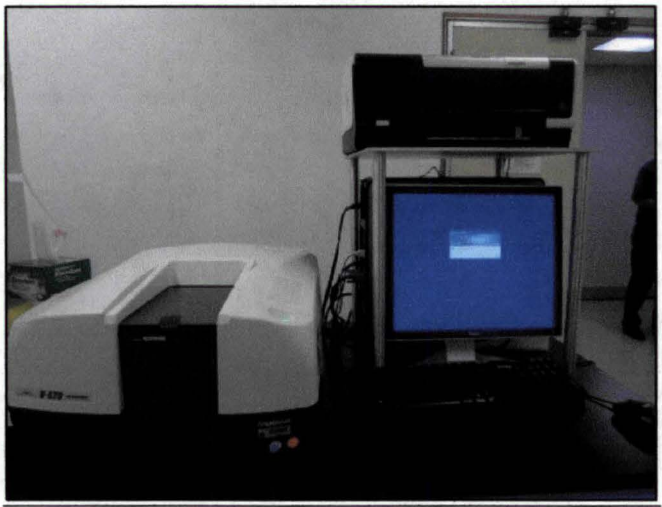


Figure 6: UV Vis/NIR instrument

Emissivity: The solar/IR reflectometer was an AZ Tek-TESA 2000 (Figure 7) and measured the emissivity, reflectivity, and solar absorptivity of the films. Emissivity is a material's ability to emit the energy absorbed[2], reflectivity is a measure of the ability of a material to reflect radiation[3], and solar absorptivity is the ratio of energy absorbed by a material to the amount of energy released at the material[4]. Each of the films was also measured for

[2] Keller HCW GmbH – Messen Publication; Py_016_e_0611; Emissivity: Definition and Influence in Non-contact Temperature Measurement

[3] English Collins Dictionary

[4] Progress in Physics; Oct. 2009; Volume 4 pg. 3-13

thickness and in the future will be evaluated by the Instron, TGA and cryogenics on down-selected materials using Cup Cryostat.

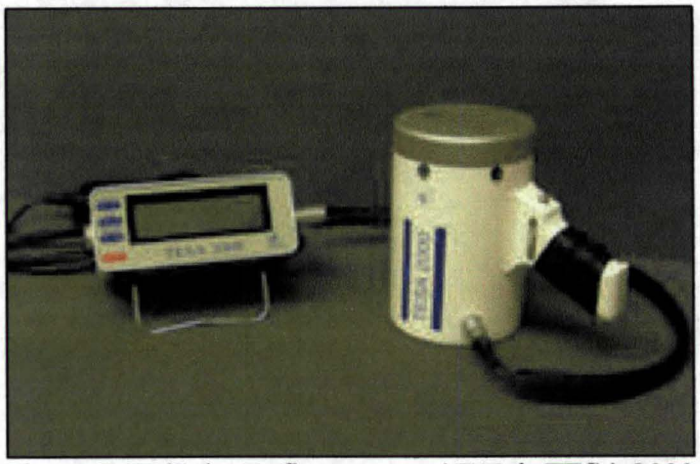
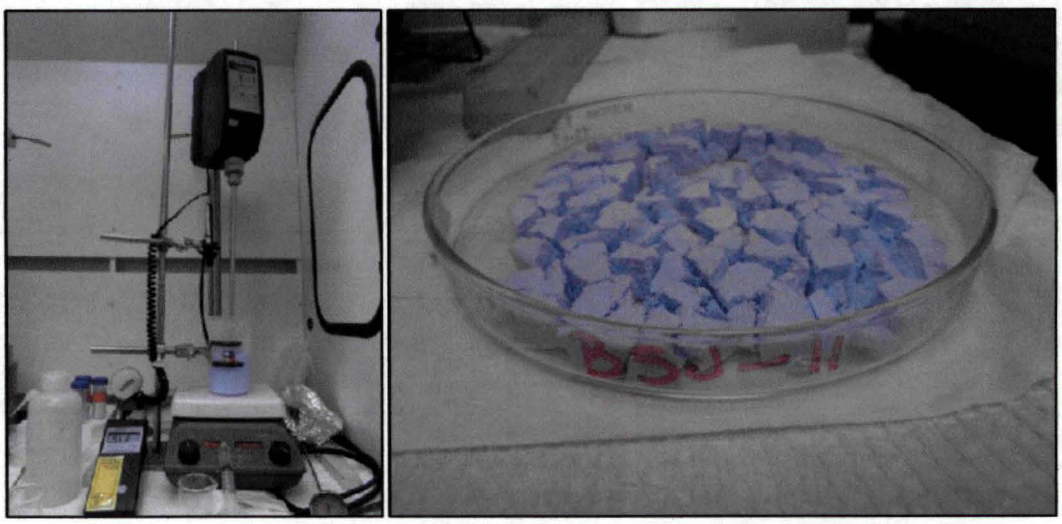


Figure 7: IR/Solar Reflectometer AZ Tek-TESA 2000

Microencapsulation

Microencapsulation was an additional project that I supported by reproducing the scale-up and synthesis of microcapsules for self-healing materials applications. The overall project task is to advance the state-of-art of microencapsulation technique from the standard spherical microcapsules to the more advanced elongated microcapsules which can be used in healant systems for wiring and flat surfaces such as inflatable structures. This project is also important to NASA's technology roadmaps and is in partnership with industry. Once the microcapsules were synthesized and isolated (Figure 8 and 9), they were characterized by SEM, TGA, and IR. This data will be incorporated into other aspects of the project for a full interpretation. It is to be noted that this type of polymer chemistry synthesis experience is extremely valuable as I move forward in my graduate studies.



Figures 8 and 9: Microcapsule Synthesis and resulting isolated product

Composites

Finally, I had the opportunity to once again provide support to the Composites Cryotank research project which I was introduced to during the summer of 2011. Thermal conductivity data was collected for the multilayer, flat composite test specimens with 3 inch diameters using the Cup Cryostat (Figures 11and 12). Materials from aerogels to metals can be tested using the Cup Cryostat. The test method is comparative; therefore requires calibration using materials with known heat transfer properties. The test conditions are representative of actual-use cryogenic applications with boundary temperatures of 293 K and 77 K. Before and after each composite sample was tested, they were imaged on the SEM. This was used to see if there were any changes occurring when performing the Cup Cryostat on the samples. Learning the cup cryostat methodology was also an introduction to future analyses that will be utilized by PSAT later in the Radiation shielding project to evaluate cryogenic thermal performance of down-selected material systems designs.

Figure 10: Cup Cryostat

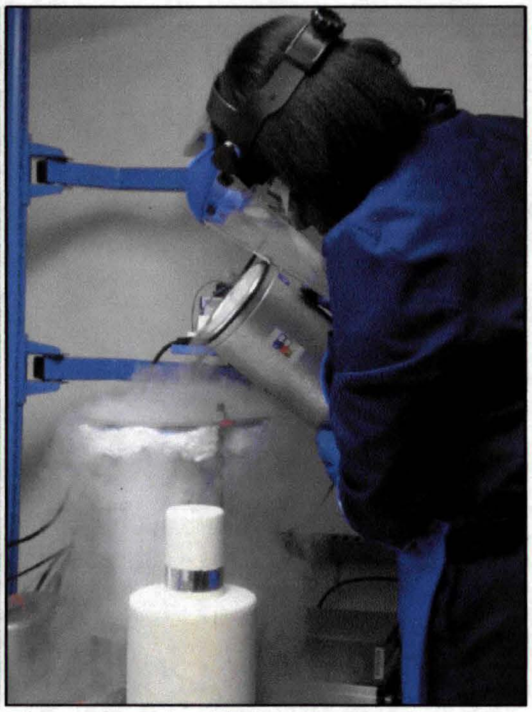


Figure 11: Liquid nitrogen for Cup Cryostat

III. Summary

I am truly grateful for the FSGC research program and the exciting opportunity it provided this summer. I learned so much and hope to have another opportunity to return to NASA and experience its innovative environment. The data collected for the "Materials Evaluation for Novel Concepts in Radiation Shielding" project is a piece of a puzzle that will be added to other pieces of a puzzle as PSAT and NASA looks forward to bringing solutions to one of NASA's top priority needs.

Materials Evaluation for Novel Concepts in Radiation Shielding

Brienne S. Johnson
Florida Space Grant Consortium
Summer 2012
Mentors: Dionne Jackson and Dr. Martha Williams

About Me

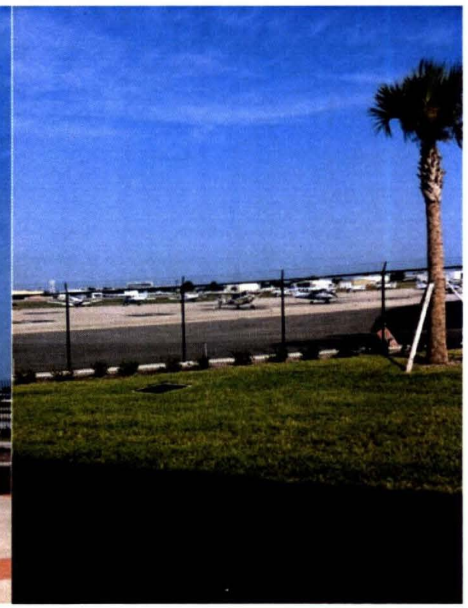
- Born: Houston, TX
- Residency: Monroe, LA
- Schools
  - Southern University and A&M College
    - B.S. in Chemistry
    - Graduated May 2012
  - University of Florida
    - PhD in Materials Science and Engineering
    - Beginning August 2012

Summer Experiences

- Launch Control Center
- Atlantis in the VAB
- Inside Endeavor
- Top of the VAB

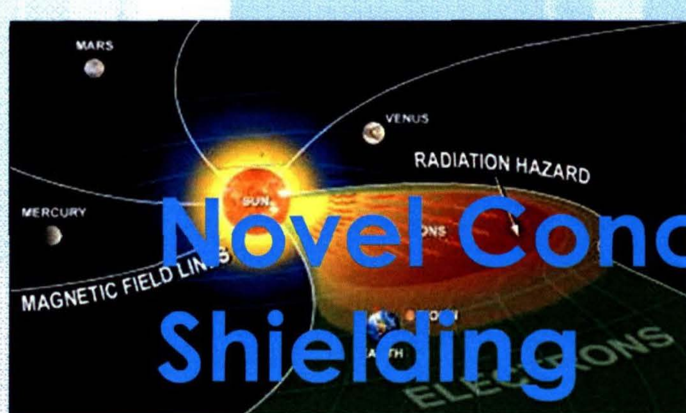
Trip to Embry-Riddle Aeronautical University

- Daytona, FL
- Visited with the Polymer Science and Technology Lab (PSAT) and Cryogenics Test Laboratory (CTL)



Summer Projects

- Novel Concepts for Radiation Shielding Materials: Primary Focus
- Microencapsulation
- Composites



Novel Concepts for Radiation Shielding

- Background
  - Radiation Mitigation for Human Spaceflight research and technology was identified as one of the top priorities by the National Research Council and NASA.
- Purpose
  - Develop materials/systems that could possibly allow containment of liquid hydrogen in new design and materials/systems.
  - FSGC summer task: testing and evaluating different state-of-the art and developmental thin-films.

Thin-Films Tested

- 27 different films evaluated including some KSC developmental materials

Teflon (MCVS005X12X6) (Polytetrafluoroethylene)

Film #1 (Ethylene-tetrafluoroethylene)

Film #2 (Ethylene-tetrafluoroethylene)

Polyvinylidene Fluoride

Polypropylene

Kapton-HN (Polyamide-imide resin)

Propylene-ethylene

Ultrason (BASF polysulfone)

Polyimide Aerogel by Glenn (GRC)

Polyimide Aerogel w/ CN by Glen (GRC)

Film #3

STJ 19-1 SPIT (150°C)
STJ 17-20 SPIF (150°C)

STJ 19-28 Soln. Imidized
STJ 11-84 Polyurethane

STJ 11-77 + Copper coated Kapton

STJ 11-80 + Copper coated Kapton

STJ 11-80 + aluminized Teflon
STJ 17-34 SPIF 3

STJ 11-75 Polyurea
STJ 11-77 Polyimide

Polycarbonate (85585K102)

Metalized Polyester 7538T11
PEEK 8504K14
PEEK 8504K16
Ultem 7576K11
Ultem 7576K13

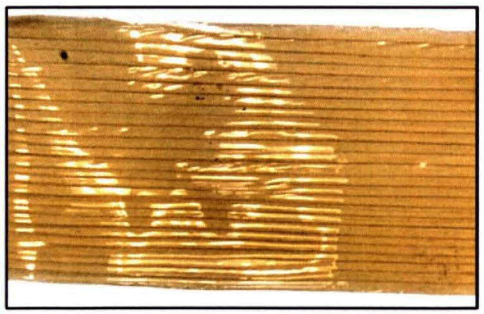
Thin-Films

Polypropylene sheet - translucent (.08mm)

Polyimide Aerogel with Carbon Nanotubes GRC - (.034mm)

Polyimide Aerogel (.045mm) by GRC

Aluminized Teflon (.063mm) with polyimide layer



KSC development STJ 19-1 SPIT (.013mm) - colored transparent

Teflon (.013mm) Partially opaque

KSC Developmental Polyimide STJ 11-77 .02mm) – colored transparent self sealing

Materials Testing

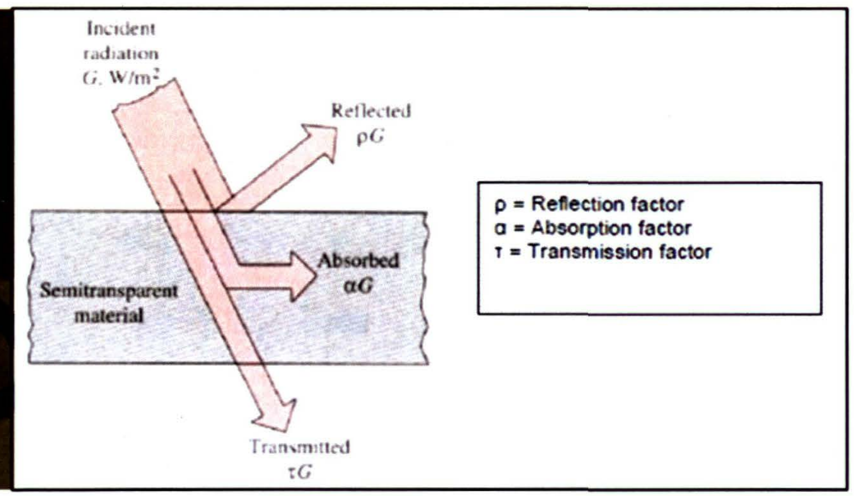
- Infrared Spectroscopy (IR)
  - Used to validate the chemical composition.

Materials Testing

- Ultra-violet Visible/Near Infrared Spectroscopy (UV Vis/NIR)
  - Used to determine where in the ultra-violet, visible and near infrared wavelengths the films absorb the light they are exposed.

Materials Testing

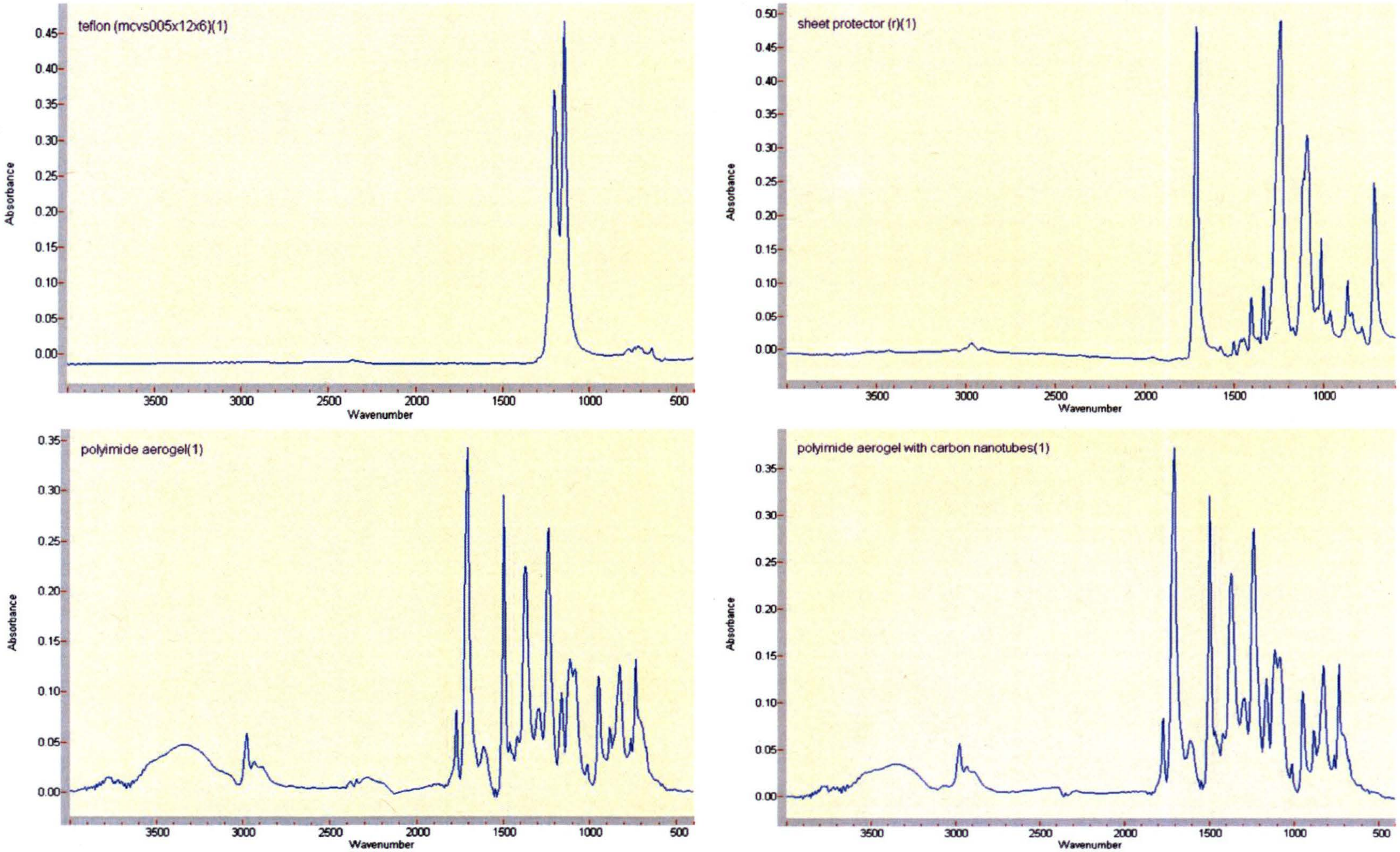
- IR/Solar Reflectometer
  - Used to determine the emissivity, reflectivity, and solar absorptivity.
  - Data collected with films against a black body



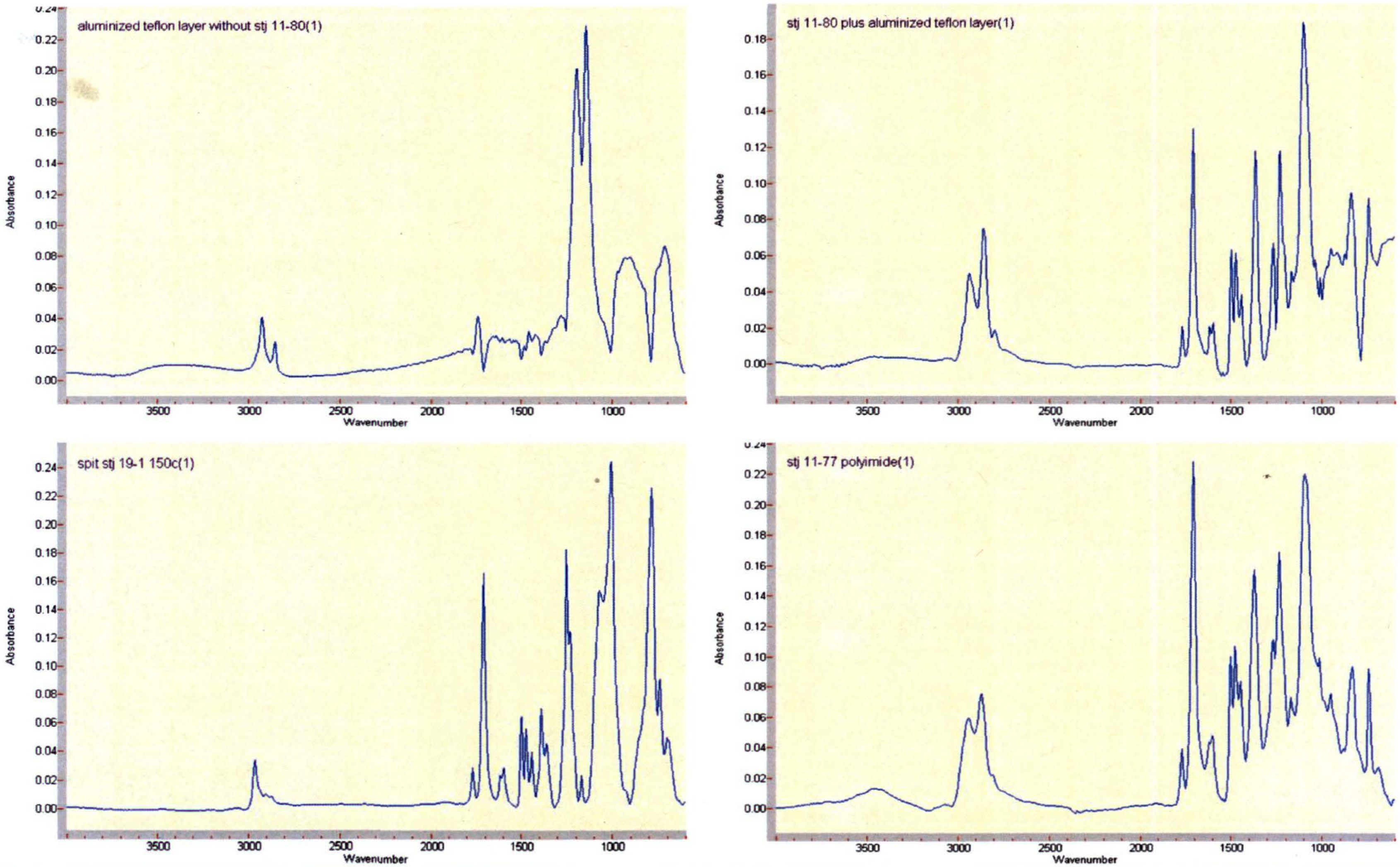
Materials Testing IR/Solar Reflectometer

- Emissivity is a material's ability to emit the energy absorbed
- Reflectivity is a measure of the ability of a material to reflect radiation
- Solar absorptivity is the ratio of energy absorbed by a material to the amount of energy released at the material
  - A true black body would have an $\varepsilon = 1$ while any real object would have $\varepsilon < 1$
  - The more reflective a material is, the lower its emissivity, for e.g. silver has an emissivity of about 0.02

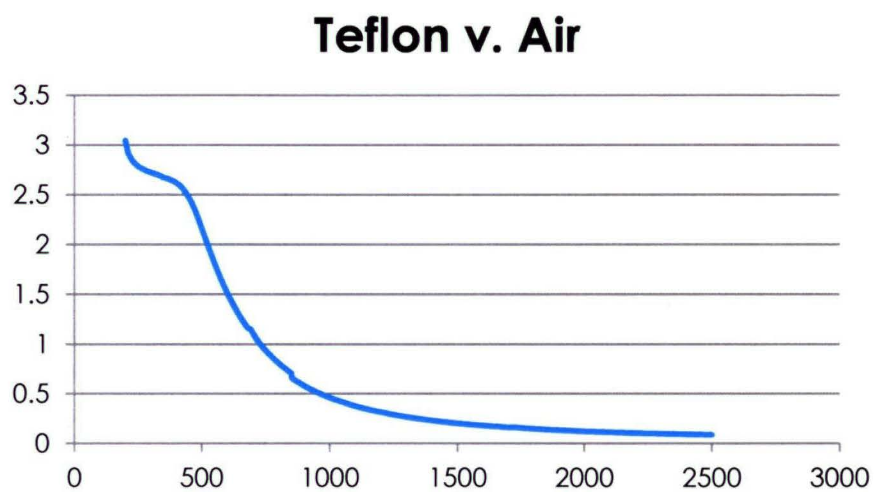
IR Results

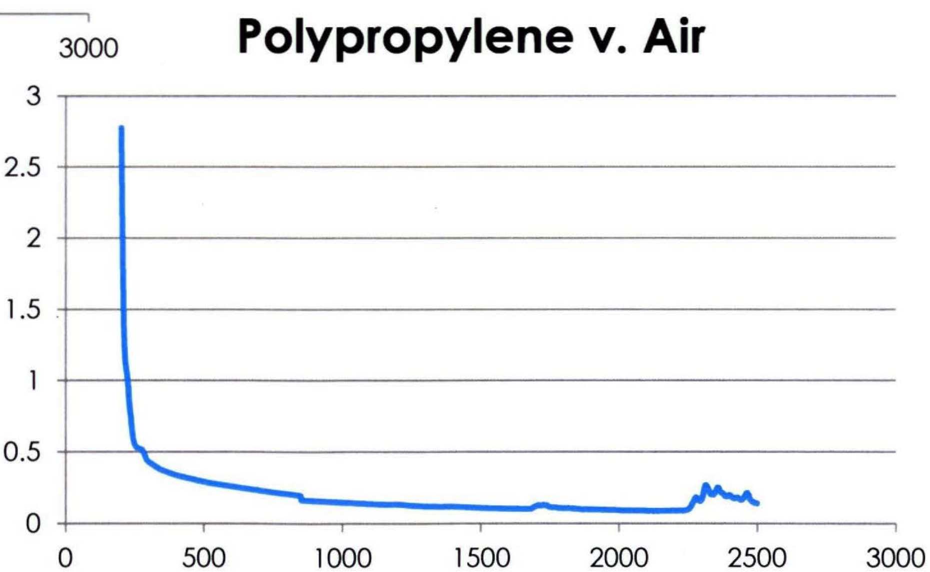

teflon (mcvs005x12x6)(1)
sheet protector (r)(1)
polyimide aerogel(1)
polyimide aerogel with carbon nanotubes(1)
Absorbance
Wavenumber

IR Results


aluminized teflon layer without stj 11-80(1)
stj 11-80 plus aluminized teflon layer(1)
spit stj 19-1 150c(1)
stj 11-77 polyimide(1)
Absorbance
Wavenumber
3500
3000
2500
2000
1500
1000

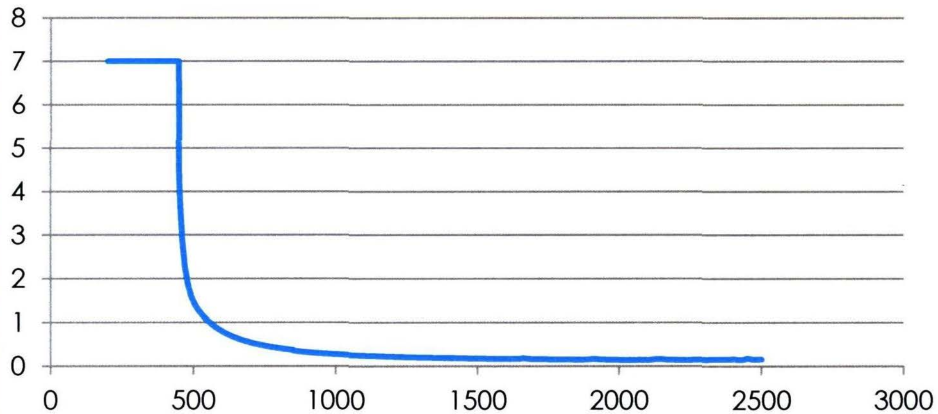
UV Vis/NIR


Teflon v. Air
3.5
3
2.5
2
1.5
1
0.5
0
0
500
1000
1500
2000
2500
3000

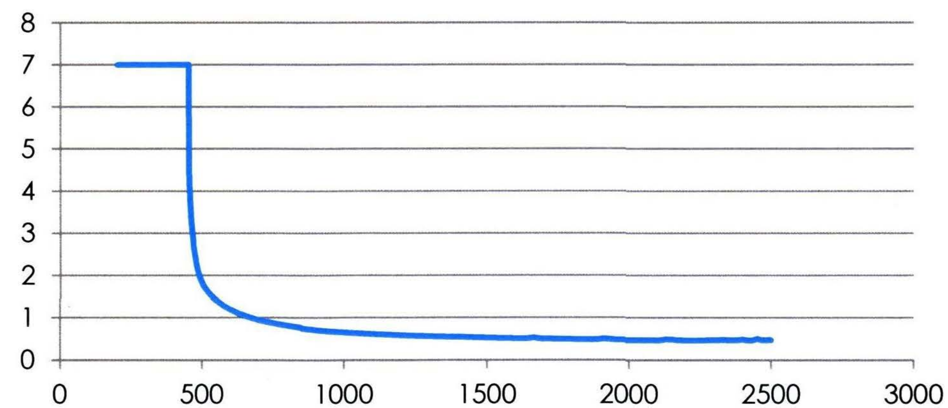

Polypropylene v. Air
3
2.5
2
1.5
1
0.5
0
0
500
1000
1500
2000
2500
3000

UV Vis/NIR

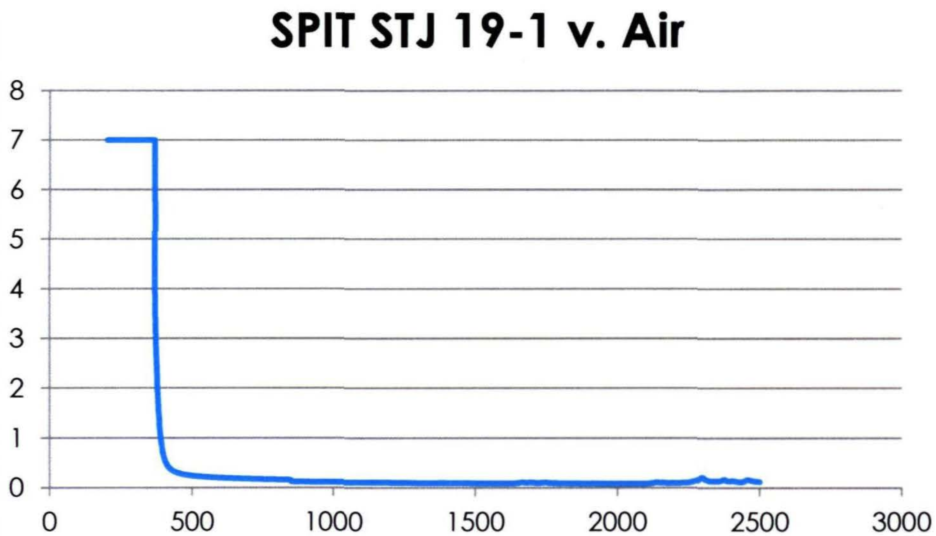
Polyimide Aerogel v. Air

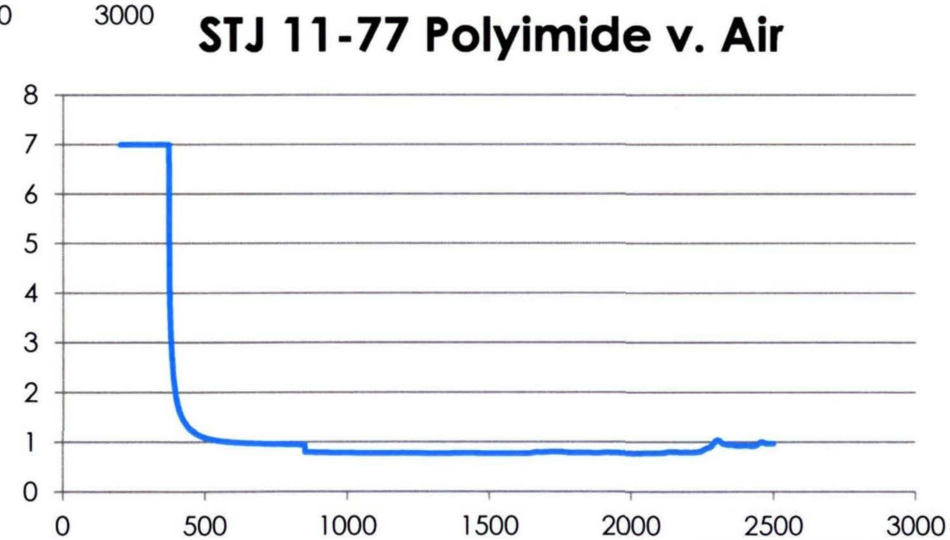


Polyimide Aerogel with Carbon Nanotubes v. Air



UV Vis/NIR


SPIT STJ 19-1 v. Air
8
7
6
5
4
3
2
1
0
0
500
1000
1500
2000
2500
3000


STJ 11-77 Polyimide v. Air
8
7
6
5
4
3
2
1
0
0
500
1000
1500
2000
2500
3000

IR/Solar Reflectometer Results

Thin-Film	Emissivity	Reflectivity	Solar Absorptivity
Teflon (MCVS005X12X6) (Polytetrafluoroethylene)	0.949	0.050	0.699
Polypropylene sheet	0.919	0.073	0.868
Polyimide Aerogel (GRC)	0.978	0.027	0.743
Polyimide Aerogel w/ CN T (GRC)	0.972	0.028	0.837
STJ 19-1 SPIT (150°C)	0.993	0.055	0.884
STJ 11-80 Aluminized Teflon Polyimide side	.944	.051	.429
STJ 11-80 Aluminized Teflon Metal Coated Side	.826	.174	.120
STJ 11-77 Polyimide	.948	.048	.878

Blackbody Reference: emissivity-0.955, reflectivity-0.045, solar absorptivity-0.95

Conclusions

- Overall the Radiation shielding project is low technology readiness (TRL) and the materials evaluation is needed for baseline of candidate materials/systems for hydrogen containment
- Data is piece of a puzzle
- Data being compared to published data where available
- Chemical compositions varied from polyolefin materials (polyethylene is a standard radiation shielding material) to metallic coated commercially available materials
- Some of the materials absorbed in the UV, visible and IR regions
- Translucent materials emissivity values are similar to the black body, the background
- Polyimide aerogels have similar reflectivity to polished surfaces
- Most differences are observed in solar absorptivity values of the different materials, dependent upon thickness
- Due to potential intellectual property certain design plans of the NASA team are not contained in this presentation

Future Work

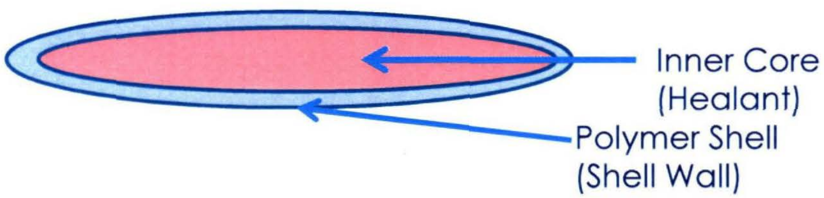
- The members of the novel materials for radiation shielding team will continue to shape unique ways of putting materials together or developing new ones to allow them to contain liquid hydrogen and a radiation shield.
- Other tests that will be conducted on the thin materials films are TGA, Instron and cryogenic testing.
- Design plans of the NASA team will continue with a slated NIAC proposal submittal on architectural design

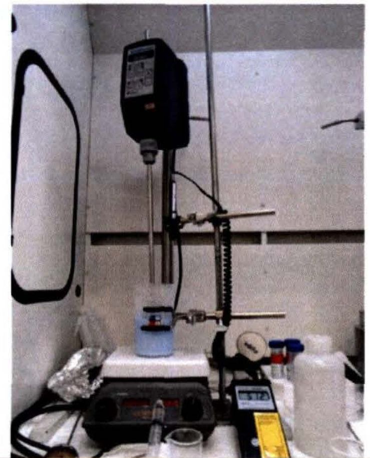
Additional Work Microencapsulation

- Purpose
  - The overall project task is to advance the state-of-art of microencapsulation from the standard spherical microcapsule to the more advanced elongated microcapsule which are used in healant systems for wiring and inflatable structures.
  - This project is also in partnership with Industry and self healing systems are important to NASA's technology roadmaps.
  - FSGC Summer Task: Reproducing the scale-up synthesis and evaluation of elongated microcapsules for self-healing materials applications.

Synthesis

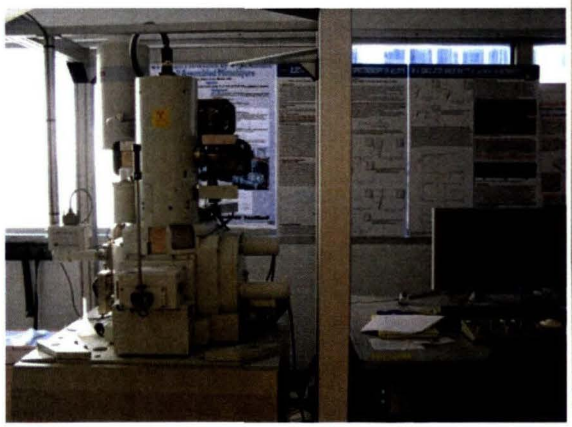
- Water phase
  - Polyethylene Oxide in water
- Oil phase
  - Epoxy
- Surfactant
- Pre-polymer (wall material)
  - Melamine/Formaldehyde





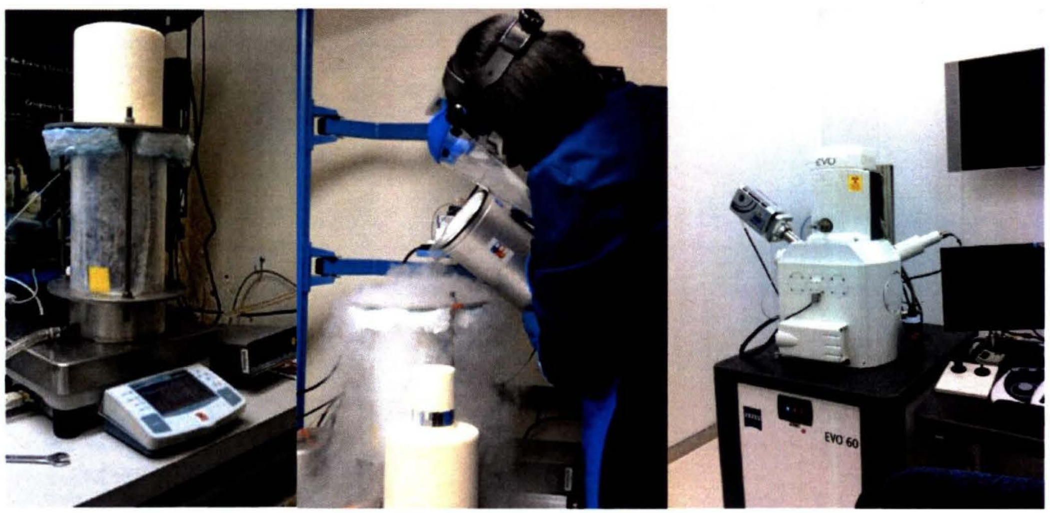
Evaluation

- Scanning Electron Microscopy (SEM)
- Thermogravametric Analysis
- Infrared Spectroscopy



Composites

- Cup Cryostat
  - A unique KSC developed technology used to measure thermal conductivity of materials.
- SEM
  - Used to image the composite disks before and after Cup Cryostat testing.



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- Dr. Tim Griffin
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